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TRANSLATION

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By

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DISCUSSION OF THE ARTICLE "CAPACITANCE D-C GENERATOR OPERATING ON A NEW PRINCIPLE" FROM "ELEKTROMEKHANIKA", NO. 10, 1959

Increasing space in the world's literature is being given to the problems of the theory and practice of designing electrostatic generators, mainly capacitance generators. This is explained, on one hand, by the increasing use of high constant-voltage generators of various capacities and the resulting increased demand for such units, and on the other hand, by the fact that the feeling of distrust for electrostatic generators, which by their very nature most completely satisfy the demands made of high-voltage units [1], is becoming a thing of the past.

Nevertheless, very little has been done in this direction, and much scientific research work remains before electrostatic generators receive the same acceptance as electromagnetic generators.

In this connection, the article by A. A. Bal'chitis concerning the problem of developing an electrostatic generator (ESG) of great power is of definite interest.

Noting certain correct conclusions of the author of the article ensuing from the general principle of the operation of a capacitance ESG, it is unfortunately impossible not to note a number of inaccuracies and errors permitted by the author that are of basic importance in estimating the actual state of the given

problem and its technological realization.

1. In the article the author raises the question of a new approach to the solution of the problem of a capacitance machine. However, it is still not clear what this approach is. If we speak of the general principle of operation of a capacitance generator, then it is far from new. In 1923 F. Ollendorf [2] published an article in which, on the basis of classical electrodynamics, he derived the basic equations for a capacitance machine (the equations for current, electric power, and mechanical force).

Later A. Ye. Kaplyanskiy [3] derived similar equations as a result of his development of a general theory of electrical machines. Finally the author himself emphasizes that one and the same principle underlies the operation of all capacitance machines. Obviously, the author should have emphasized something else, namely a further development (refinement, clarification, particular and general interpretations) in the description of the phenomena inherent in the capacitance machine. But there is also much vagueness in this question.

The magnitude of the charge q and the quantities γ and E_1 introduced by the author are irrelevant and unrelated to anything. Judging from the theoretical and calculation parts of the article $E_1 = E_t$, where $E_t = 0.1E$, where E is the operating electric field strength in the gap of the machine. But an explanation of the relationship between E_1, E_t, and E, as well as an indication of the site of application of the forces caused by the action of the vector components of the electric field strength, are wanting.

It is known, however, that in an ESG with transporter-conductors, useful work is expended on overcoming only those forces which act in the direction of motion of the transporter, i. e., toward its face. Therefore in order to assure

maximum forces (and to obtain the maximum power of the ESG) the transporters are given dimensions and shapes such that the electric field strength is maximum (close to the dielectric strength of the medium) over the entire surface of the transporter, including its face [4]. This position also remains in force when the elements of the rotor fulfill the role of charge exciters.

The author side-steps these questions. In general, a division into normal and tangential components of the field strength is resorted to only when considering the phenomena in generators with a transporter-dielectric, where this has direct significance and where the tangential component of the field strength actually reaches a value of the order of 0.1E or more.

If by a new approach the author means the description of the very simple capacitance system shown in Fig. 1 of the article, then this is several steps backward.

First, an analogous design using rectifiers in the circuit of the stator plates and excitation of the rotor has already been described [5].

Second, the author in his circuit does not provide for control of the rectifiers without which it is impossible to expect production of the maximum possible power of the generator. This is easy to show by means of A. F. Joffe's method [6].

The relation $q = CU$ is used in all capacitance systems. At the initial moment of the operating cycle of the generator, when only the excitation voltage U_1 is applied to the system of plates of the generator, the maximum charge $q = C_1U_1$, where C_1 is the maximum capacitance of the system, is stored in the system. In the succeeding moments of the operating cycle increases in the voltage of the system are attained by regulating the ratio between $\underline{q}$ and C, after which the charges are shunted to the load circuit.

An attempt is made to maintain for as long as possible the maximum value $q = q_1$ while simultaneously decreasing the capacitance C. Hence in the stated problem steps were taken to obtain the greatest voltage or greatest power in the load circuit. The greatest power, for example, under ideal conditions and according to the elementary circuit of a disk generator is produced by decreasing the capacitance to half the maximum while maintaining the maximum charge [7].

Consequently, the moments of commutation are also calculated: in commutator machines the moment of contact of the brush with the commutator, and in rectifier machines the moment of firing the rectifiers. In circuits with uncontrolled rectifiers, a decrease in capacitance causes a simultaneous decrease in the charge, since the load is already connected. As a result, the power of the machine is reduced, since the maximum power (less than the possible) is attained at the decreased voltage. True, the desired voltage can be produced by an increase in the load resistance, but this will reduce the output power of the generator still more. Therefore in Trump's generator controlled rectifiers were used [5].

Third, the use of a "dead" stator plate in the author's circuit is completely superfluous. Leakage fluxes are sufficient to provide a closed current circuit. This is what Malek [8] used in an analogous design of a disk ESG, in which the second half of the stator as well as the first half, is a working half. We are discussing an analogous design, since nothing prevents Malek's commutator system from being replaced by a rectifier-control system. In this case the circuit of the elementary generator with two plates on the stator and one on the rotor will contain four rectifiers: two grounded and two "high-voltage", one of each in circuit of each stator plate. Rectification will not be half-wave but full wave,

and to produce a constant but not intermittent current it will not be necessary to have an additional such machine or to have in one doubled machine two elementary circuits with "dead" plates, as the author proposes.

2. The idea of developing an ESG of great power for energetic purposes has been nurtured for a long time and, as we may note, always in a long-term plan. Thus Academician A. F. Joffe wrote that to him "... electrostatic generators of thousands and tens of thousands of kilowatts are completely possible"[6]. A. Ye. Kaplyanskiy, calculating a synchronous capacitance generator for 100,000 kw pointed out especially that this calculation lays no claim to be capable of actual fulfillment[3].

Trump, who already had experience making small capacitance generators in a vacuum, also only assumed that if it were possible to insulate in a high-vacuum a voltage of $1 \cdot 10^6$ v with a field gradient of $1 \cdot 10^6$ v/cm, it would be possible to construct an ESG with $U_2 = 500$ kv when $U_1 = 500$ kv. If the rotor consists of 50 disks with inner and outer diameters of 60 and 120 cm, respectively, each having 16 sectors, then at n = 4000 rpm the power of the generator should be about 7000 kw [5]. These data, although they are closer to the actual data, are, nevertheless, still far from them. Actually, the prospects of using a vacuum as insulation at the present time are no closer to realization than they were in the 1930-1040's. The recent investigations of breakdown in a vacuum conducted at the KhFTI [9] confirm the results obtained earlier [10].

These data are: with a vacuum of from 10^{-6} to 10^{-8} mm Hg and with a distance between the electrodes of 1 mm $E_{br} = 1 \cdot 10^6$ v/cm, and when $\delta = 7$ mm, $E_{br} = 3.6 \cdot 10^5$ v/cm. In this case large leakages of current are noted long before breakdown in the gap of the sphere opposite the plane[9]. We must expect

a considerable increase in current leakages, if the gap is produced by planes with a large surface such as occurs in the ESG disks.

In the opinion of Academician A. K. Val'ter [1], the use of a vacuum insulation in an ESG at the present time is not justified. Under these conditions the author proposes a plan for an ESG of 2 million volts with a power of 200,000 kw, using a vacuum with an electrical strength $E_{br} = 10 \cdot 10^6$ v/cm, and asserts that such an ESG will be widely used, virtually resting his assertion on the single factor of the low weight of the active material used per unit of power. Meanwhile, this description is not and cannot be exhaustive. It only points out the theoretical possibilities of an ESG, the ability of an ESG to compete with other methods of producing electrical energy.

The advantages of electrical power units are more fully determined by the conditions of operation, reliability, and other such features. In this respect the use of high-voltage rectifiers in a capacitance EGS and the need for continuous evacuation greatly reduces its superiority over transformer-rectifier units, especially when we are dealing with rectifiers of a million volts and with large evacuation volumes. In this case we must at least have a definite economic calculation and a comparison of variants.

Nor can we forget the existing experience in designing multidisk generators acquired all over the world. Studies of recent years showed [11] that great difficulties arise in designing multidisk generators with a power of only 1 kw. Since the disks of the rotor must be insulated from the axle, it is difficult to prevent them from bending as a result of random or unavoidable deformation of the insulating attachments. This danger considerably increases for generators whose rotor weight is reckoned in tons.

Another disadvantage of the multidisk generators is the fact that the probability of random breakdowns between the disks of the rotor and stator increases with

an increase in the total area of the disks. We may expect this phenomenon to be intensified in a generator of great power and super-high voltages, having an extremely developed surface and operating in a vacuum.

Therefore only further practical development of generators of various designs, and not farfetched projects, can pave the way to developing really powerful and highly economic electrostatic sources of high constant voltage.

3. A serious defect of the article is the inaccuracy of the generator calculation.

A characteristic phenomenon in generators with a transporter-conductor is that the field strength caused by the appearance of the working voltage is superimposed on the excitation field. Since the polarities of the excitation and load voltages are of opposite sign, the following condition must be maintained

$$E\delta = |U_2| + |U_1|, \qquad (1)$$

hence

$$U_1 = E\cdot\delta - |U_2|,$$

then, since the author calculates the excitation voltage from the formula

$$U_1 = E\delta.$$

It follows from condition (1) that it is absured to speak of an output voltage of 2 million v when $\delta = 0.7$ cm. On the other hand, the author completely failed to justify the choice of the value $U_2 = 2$ million v. With equal success the value of U_2 could be assumed to be 5 and even 10 million v, and the value $l_c = \frac{2U_2}{E_t}$ could be calculated correspondingly according to the author's method. The actual values of U_2 and U_1 can be obtained by using equation (1). If according to

the authors circuit we anticipate the generation of maximum power, then U_2 will be considerably less than U_1, and neither one nor the other will exceed the value $U_0 = E\,\delta$.

In calculating the power of the generator, the author uses the maximum instantaneous value of the current and claims it to be the average value. Actually, considering that rectification of the current in the author's generator is half-wave and assuming that the shape of the curve of the current is sinusoidal, which is close to the truth, the formula for the average value of the current (taking into account both sides of the rotor's disk) is written as

$$i_{cp} = \frac{1}{2\sqrt{2}} \omega (R_1^2 - R_2^2) \varepsilon_r \varepsilon_0 E,$$

i.e., in order to produce a rated current of 50 amp, the number of rotor disks in the author's generator must be almost tripled. If we anticipate the generation of a rated power of 100,000 kw and take into consideration that the actual voltage is considerable and periodic, moreover, like the current, the number of disks must be increased several times more.

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1. "A capacitance machine operating on a new principle based on the induction of a current in a conductor moving in an electric field", as A. A. Bal'chitis writes, is not new, since all capacitance machines are based on the induction of a current in conductors moving in an electric field.

The generator circuit proposed by the author, if we throw out his rectifiers, which are of no fundamental importance, is a unipolar machine and is, so to speak, half of the bipolar machine considered by F. Ollendorf [1] and A. Ye. Kaplyanskiy [2].

In this machine the capacitance between the stator plate and the rotor plate varies from C_{max} to $-C_{max}$, while in the machine proposed by A. A. Bal'chitis the capacitance varies from C_{max} to C_{min}; and, given the same dimensions and field strength in the gap of the stator-rotor, we obtain a reduction of more than half in the current induced by the generator (short-circuit current). In addition,

in the author's machine the current is used during only half the period and, consequently, the resulting decrease in the current and the power will be a factor of about five. Thus, the machine proposed by the author is a step backward in comparison with the machine considered by Ollendorf.

The author's machine, as well as Ollendorf's machine, has the following disadvantages: 1) the maximum voltage (the open circuit voltage) is less than the excitation voltage U_S; 2) the external characteristic of the machine U(I) with constant excitation voltage and rotational velocity is steep due to the severe effect of the armature reaction, i. e., the additional field in the gap changing the original field of excitation; 3) the alternating component of the current of the excitation circuit equals the current in the load r.

2. The author speaks of the possibility of developing a capacitance commutatorless direct-current machine. However, as early as 1907 P. Barkhausen [3] and A. Poincaré [4] proved that the mutual transformations of mechanical and electrical energy in a capacitance system are possible only with alternating currents in the system, and with direct currents the system must contain variable resistors, i. e., a commutator.

Thus a commutatorless d-c machine is impossible in principle; the presence of only variable capacitance, as the author describes, is inadequate for this purpose; it is adequate only for transformation of energy with alternating currents. The impossibility of generating a direct current by a capacitance generator without commutation can be shown quite elementarily.

Since the current

$$i = \frac{dq}{dt},$$

then the requirement i = const = A leads to the need for a boundless increase of the charge in time

$$q = At + q_0,$$

which is physically impossible.

In the machine proposed by the author as commutatorless there is actually a commutator--its role is assumed by the rectifiers.

Thus the machine proposed by the author is in essence a high-voltage rectifier in which the capacitance machine itself is the source of alternating current. Aside from the fact that rectifiers for voltages of the order of a million volts are presently non-existent, apparently it is simpler and more advisable to use in the rectifier as a source of high-voltage alternating current not a capacitance machine but an ordinary generator and transformer. The author's circuit is also unsuccessful in that with two rectifiers only half-wave rectification is produced.

3. In his approximate calculation of a vacuum capacitance generator the author obtained a very small weight of the machine per unit of power--0.02 kg/kw. Such a result, although astounding at first glance, is explained by the fact that the author incorrectly determined the permissible field strength in the gap of the machine and its power.

First, the author started from an unrealistic value of the permissible excitation voltage of $1.4 \cdot 10^6$ v with a gap of $\delta = 7$ mm.

According to the data of Trump and Van De Graaff for steel electrodes in the form of a sphere (diameter 25 mm) or a disk (diameter 50 mm) the breakdown voltage of a vacuum at $\delta = 7$ mm is about 250 kv which is 1/5.6 times the value of the excitation voltage taken by the author. Consequently, the excitation voltage should be no more than 1/10 that taken by the author: the power is decreased

100 times as much as the current and the voltage of the machine.

Second, the author in his calculation did not account for the armature reaction (voltage reaction), i. e., the additional field in the gap changing the original excitation field, and it would have proved to have a considerable effect on the value of the current of the machine by decreasing it.

Therefore the power of the calculated machine is considerably less than the initial value of 100,000 kw, and the weight per unit of power will be greater than that obtained by the author.

4. In his conclusions the author writes that by introducing electrets into the capacitance machine, it can be made self-exciting. Actually, given certain relationships between the parameters of the excitation circuit and the armature circuit a capacitance machine, even one not containing electrets,, can operate with self-excitation in any circuit--series, parallel, or mixed. However, neither Ollendorf's machine nor the author's machine can be self-excited, since their voltage is always less than the excitation voltage.

In conclusion, we may say that A. A. Bal'chitis' article contains a number of important errors and does not contribute to the solution of the highly interesting problem of developing high-voltage capacitance machines.

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